Computational Modeling of Chemical Protective Clothing

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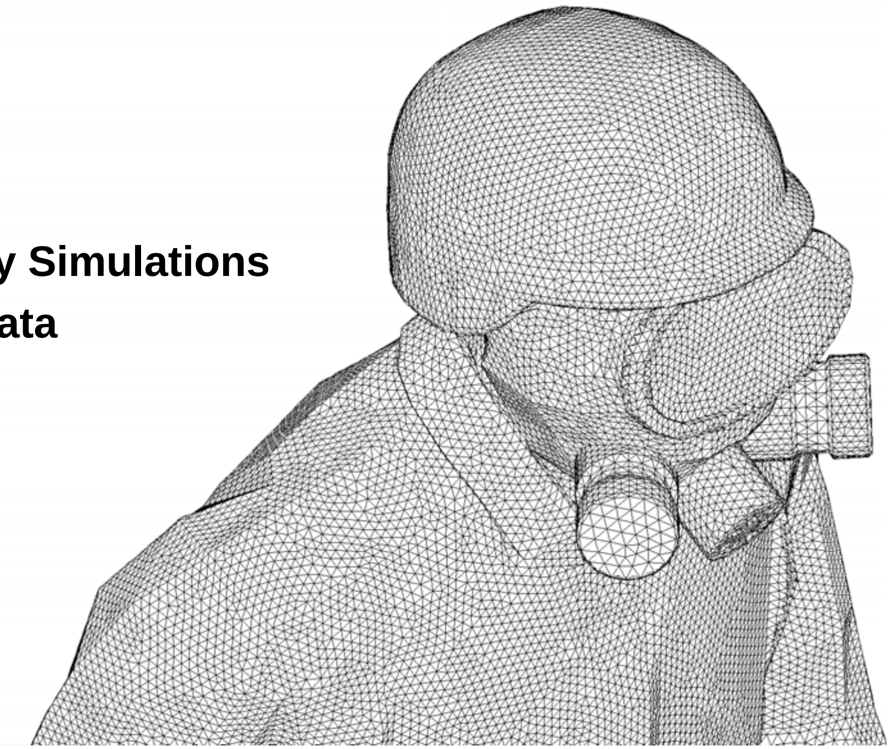
Introduction

- **Computational Modeling of Clothing Performance**
  - **Utilize Computational Fluid Dynamics (CFD)**
  - **Initial Focus on Chemical/Biological Protective Clothing**
  - **Modeling Tools Developed Have Broader Application**

- **Scope of Work**
  - **CFD Software Enhancements**
  - **2-D/3-D Clothed Human Models**
  - **Sensitivity Studies and Exploratory Simulations**
  - **Validation Against Experimental Data**

- **Supported by CBD/Army SBIR (SBCCOM-Natick)**

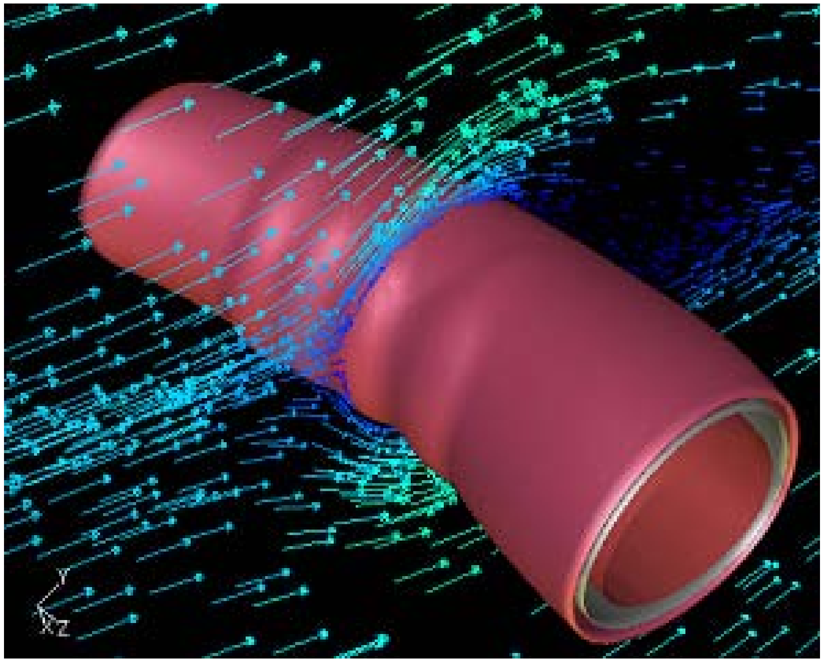


Objectives of Computational Modeling

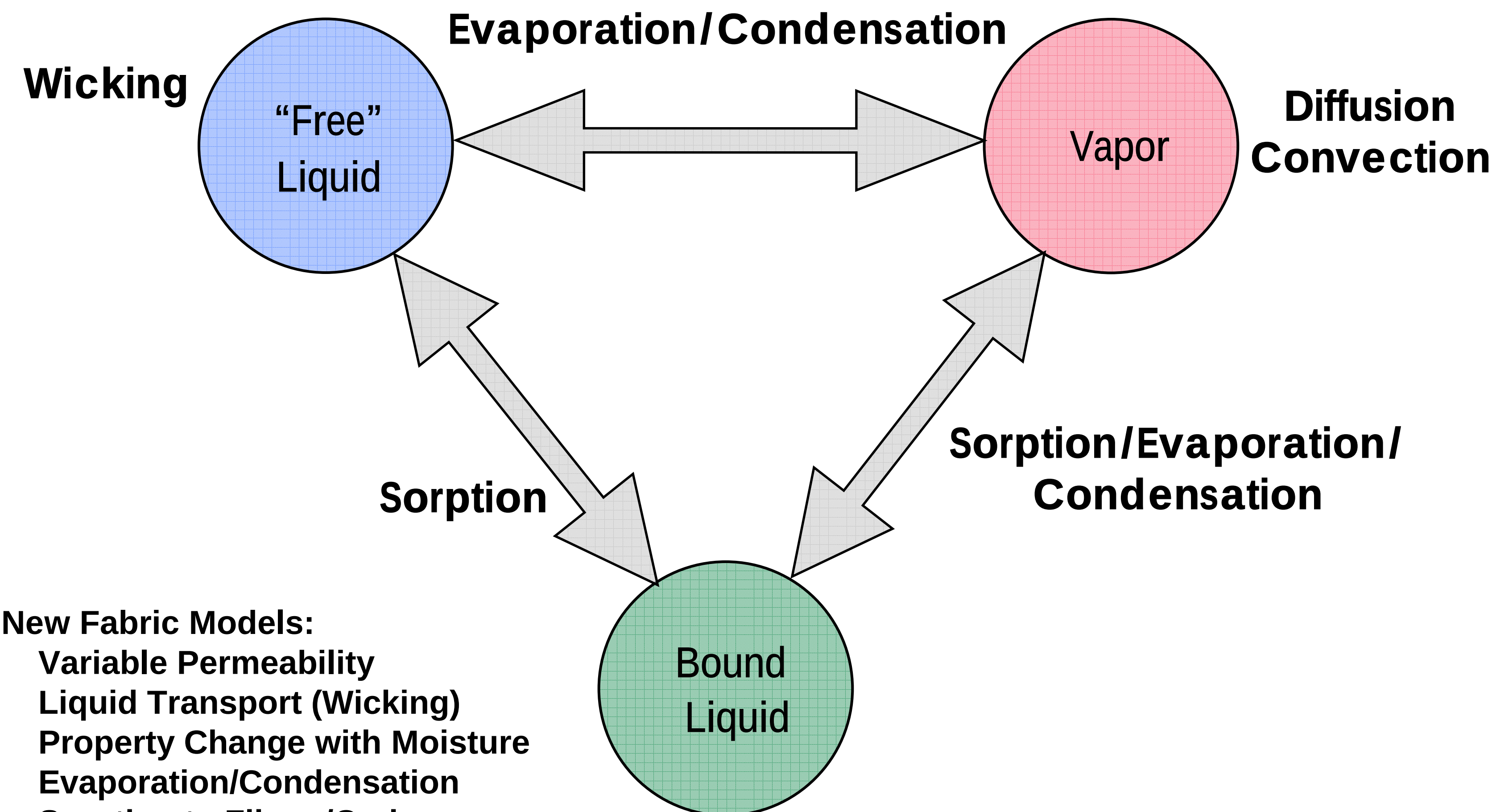
- **Address Thermal/Fluid Issues in Protective Clothing**
  - **Protection from Chemical/Biological Agents**
  - **Thermal Impact on Clothed Soldier**
- **Evaluate Clothing Designs/Protective Strategies**
  - **Fabric Characteristics**
  - **Clothing Geometry and Layering**
  - **Environmental Conditions**
- **Excellent Complement to Lab/Field Tests**
  - **Idealized Geometry and Boundary Conditions**
  - **“Perfect Instrumentation”**
  - **Visualization of Complex Flow Fields**
  - **Cost Effectiveness**

Technical Approach

- **CFD Simulations**
  - **Solve 3-D Mass/Momentum/Energy Equations**
  - **Volume-Averaged Porous Media Approach**
  - **Extend Commercial FLUENT® Software for Vapor/Liquid Physics in Fabric**
- **Mix of Geometries**
  - **2-D Body Section**
  - **3-D Partial or Full Body Models**
  - **3-D Model of Exterior Surface**
- **Encompass Range of Physics**
  - **Basic Air Flow and Heat Transfer**
  - **Sweating and Thermal Balance**
    - » **Evaporation/Condensation**
    - » **Sorption and Wicking**
  - **Agent Transport and Absorption**
    - » **Aerosol/Liquid/Vapor**
    - » **Activated Carbon**



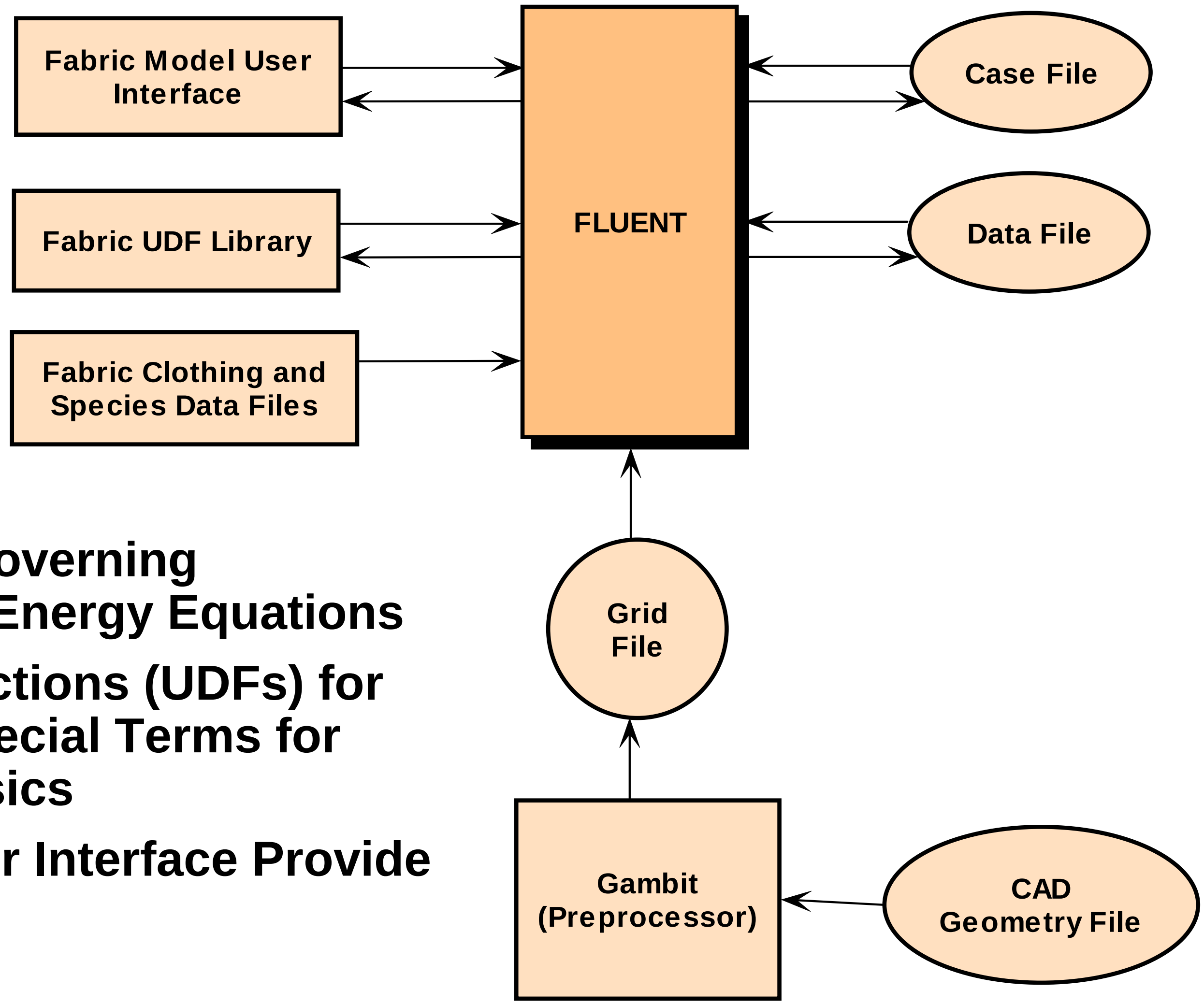
Transport and Phase Change



New Fabric Models:
- **Variable Permeability**
- **Liquid Transport (Wicking)**
- **Property Change with Moisture**
- **Evaporation/Condensation**
- **Sorption to Fibers/Carbon**

Approach Applicable to Water or CB Agents

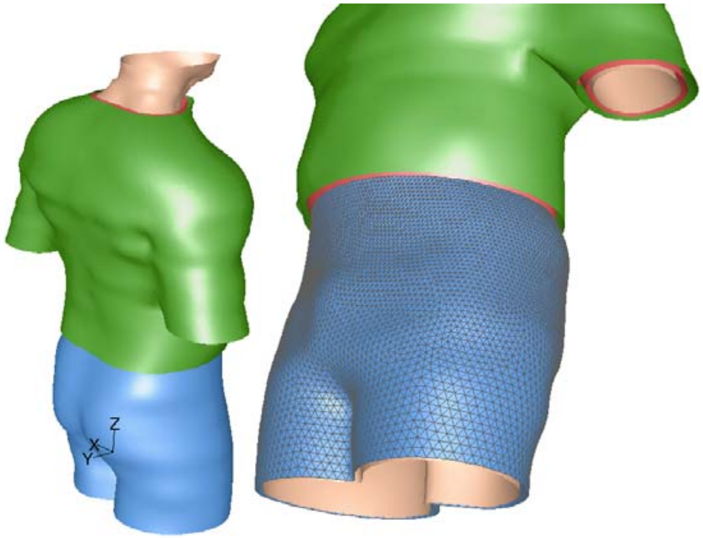
Integration With FLUENT

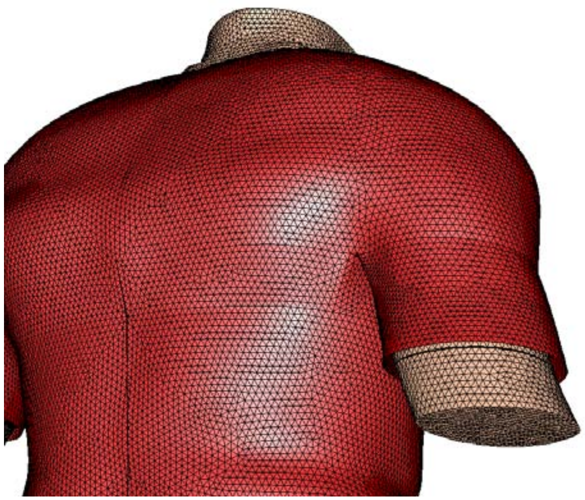


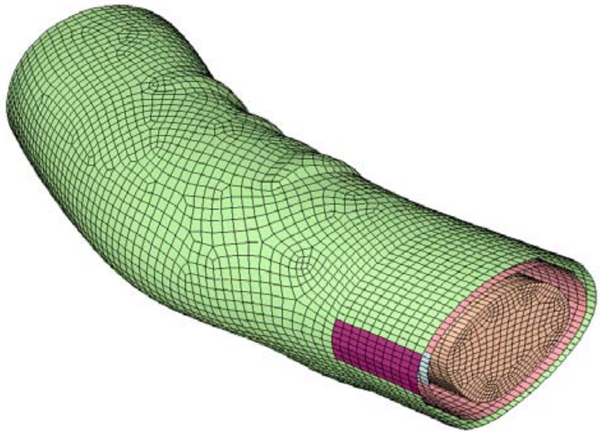
- **FLUENT Solves Governing Mass/Momentum/Energy Equations**
- **User-Defined Functions (UDFs) for Fabric Provide Special Terms for Vapor/Liquid Physics**
- **Extensions to User Interface Provide Access to Models**

Models of Clothed Humans

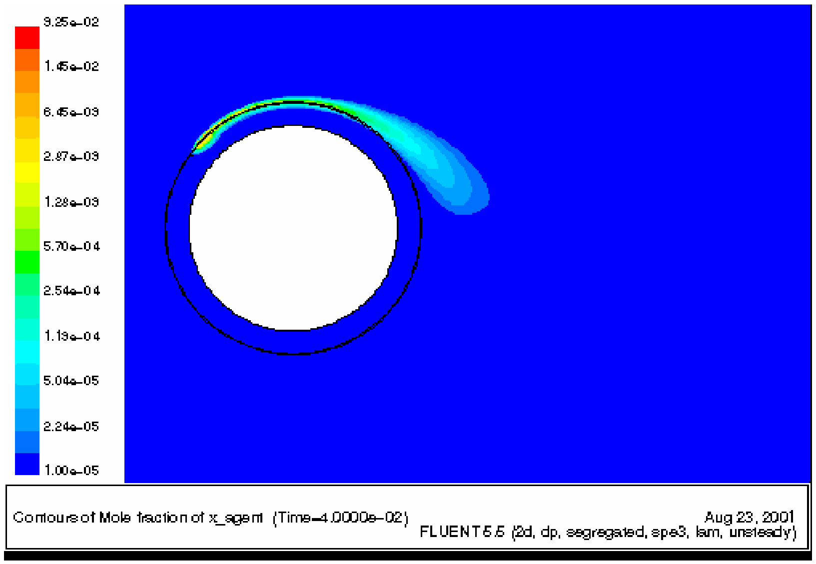
- **Geometry/Grid Models Developed**
  - **Arms With One/Two Clothing Layers and Two Types of Wrist Closures**
  - **Torsos With One or Two Clothing Layers**
  - **Kneeling Soldier (No Detailed Clothing Layers)**
- **Most Models Created from Laser Body Scans, Then Meshed in FLUENT**

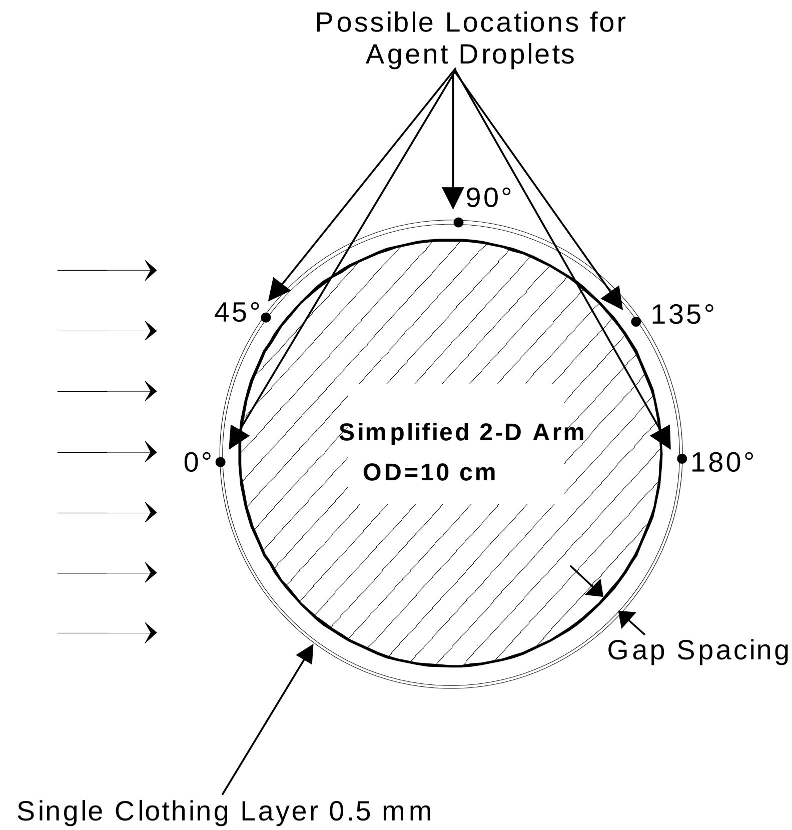






Idealized Arm With Agent Droplet



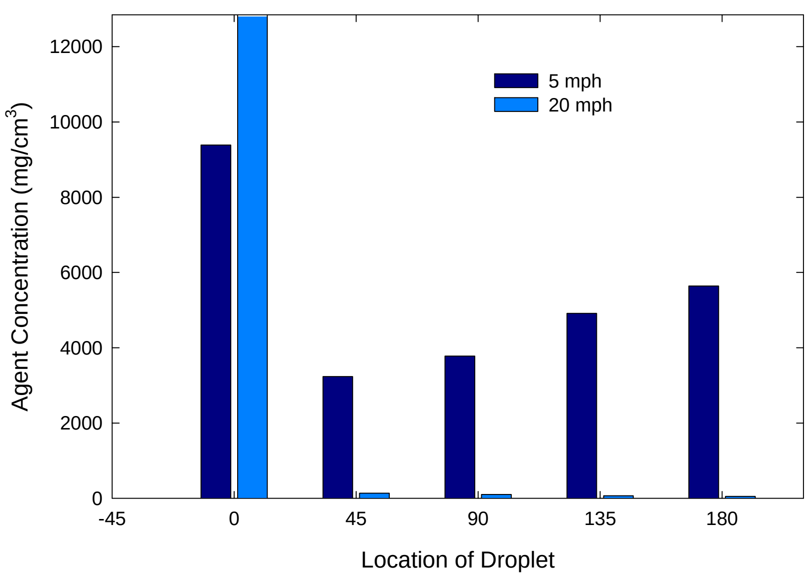


- **Two Wind Speeds (5 & 20 mph)**
- **Sensitivity:**
  - **Droplet Location**
  - **Clothing Gap Width and Uniformity**
  - **Multiple Clothing Layer**
- **No Absorbent**

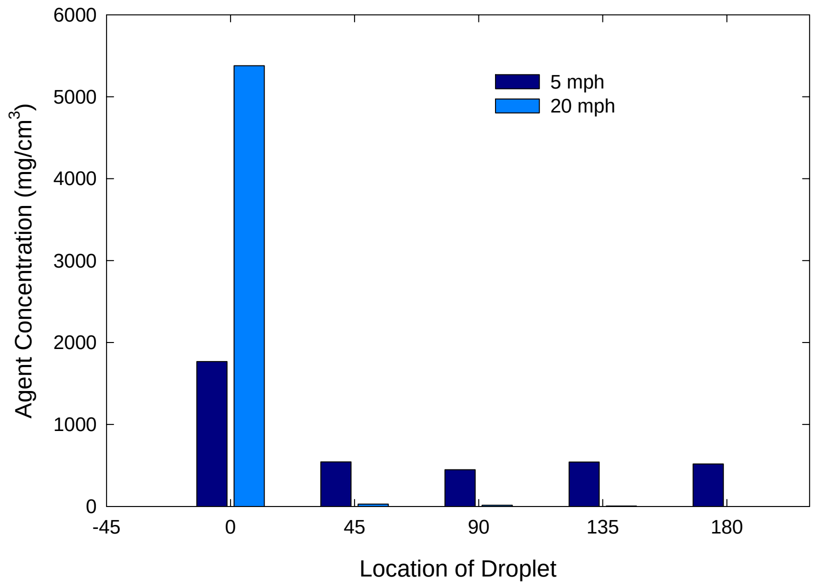
Wind Speed and Droplet Location

- **Worst Case Droplet Location—Stagnation Point (0°)**
- **Effect of Wind Speed Depends on Droplet Location**
  - **Stagnation Point: Higher Speed ⇒ Higher Penetration**
  - **Elsewhere: Higher Speed ⇒ Greater Dilution**
- **If Absorbent Is Used, Local Overload Also Becomes Concern**

Maximum Concentration at Arm Surface

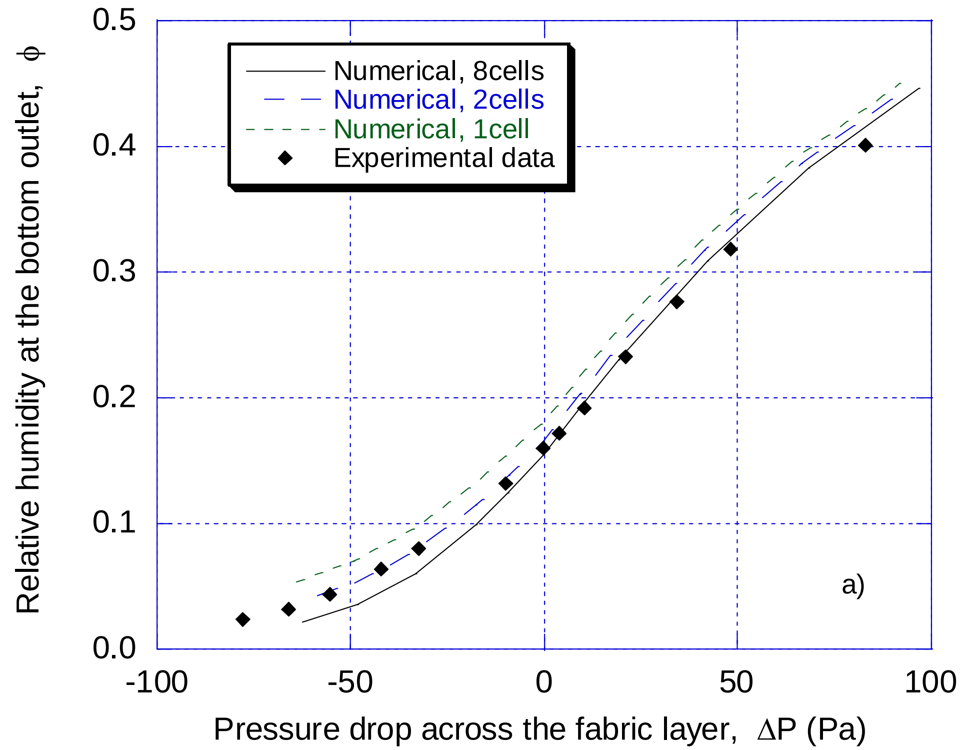


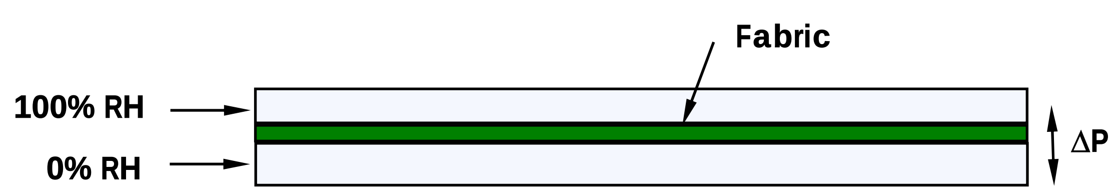
Average Concentration at Arm Surface



Comparisons With Natick DMPC Data

- **Steady State**
  - **Cotton Fabric 0.384 mm Thick**
  - **0.57 m/s N_2**
    100% Relative Humidity Above
  - **0.57 m/s N_2**
    0% Relative Humidity Below
- **Outlet Resistance Varied to Force Flow Through Fabric**
- **Test of Variable Flow Resistance With Fabric Regain**
- **Good Agreement With Experimental Data**





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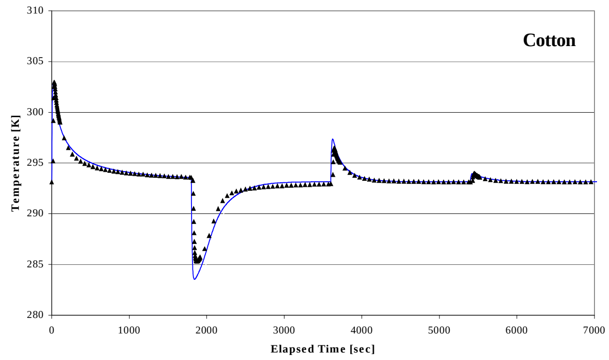
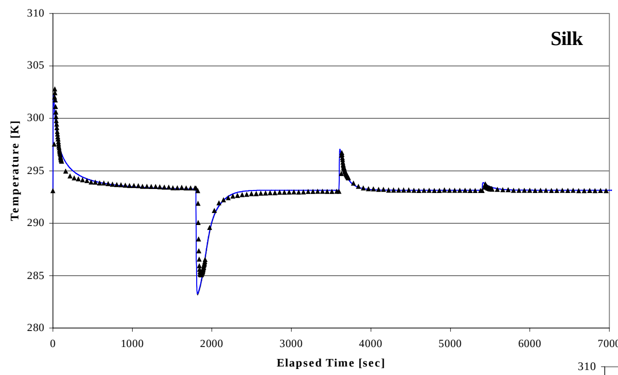
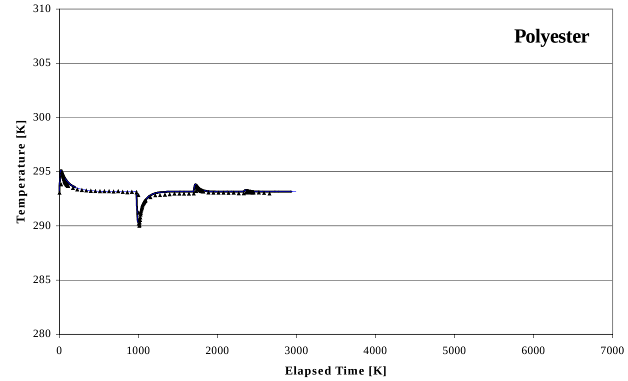
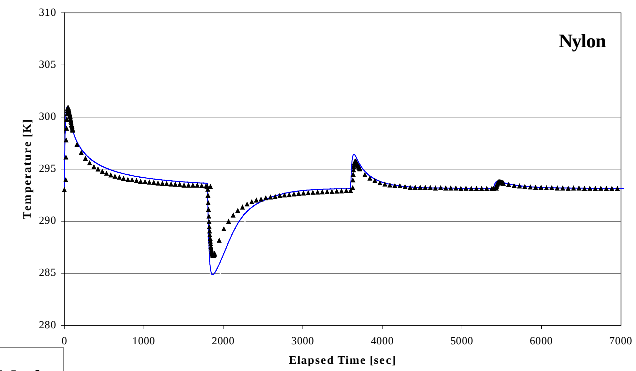
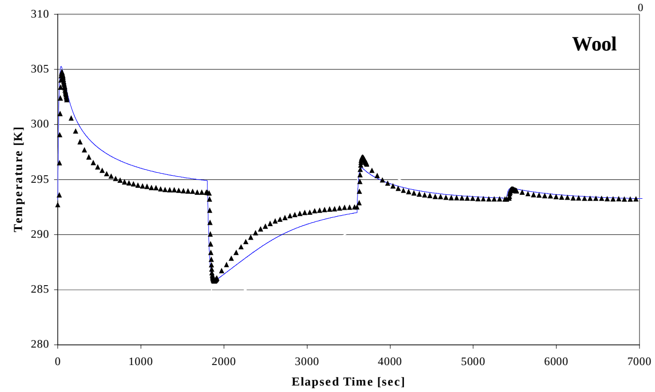




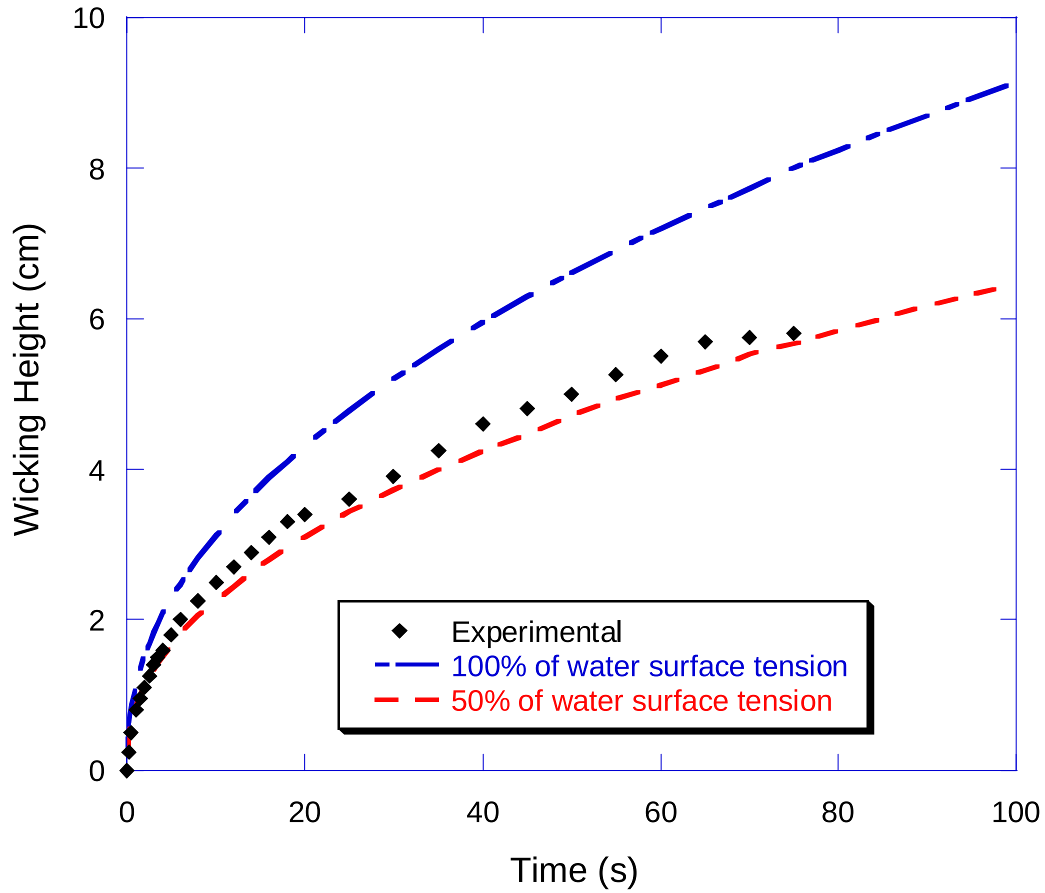
- **Response to Step Changes in Humidity**
- **Rise/Fall Profiles of Temperature Well-Matched by Model**



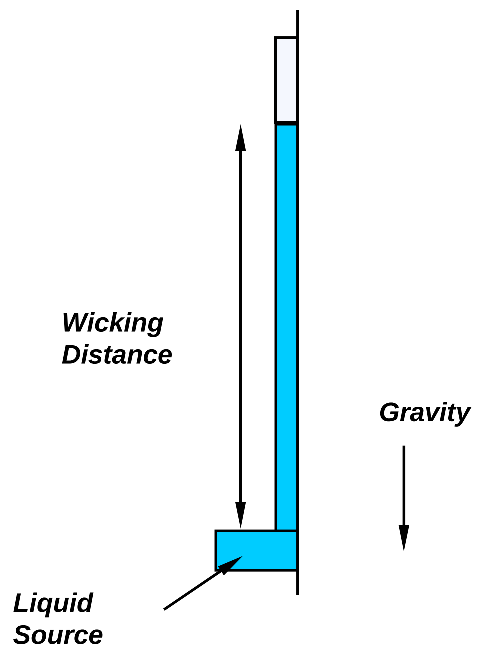




Comparison to Wicking Data

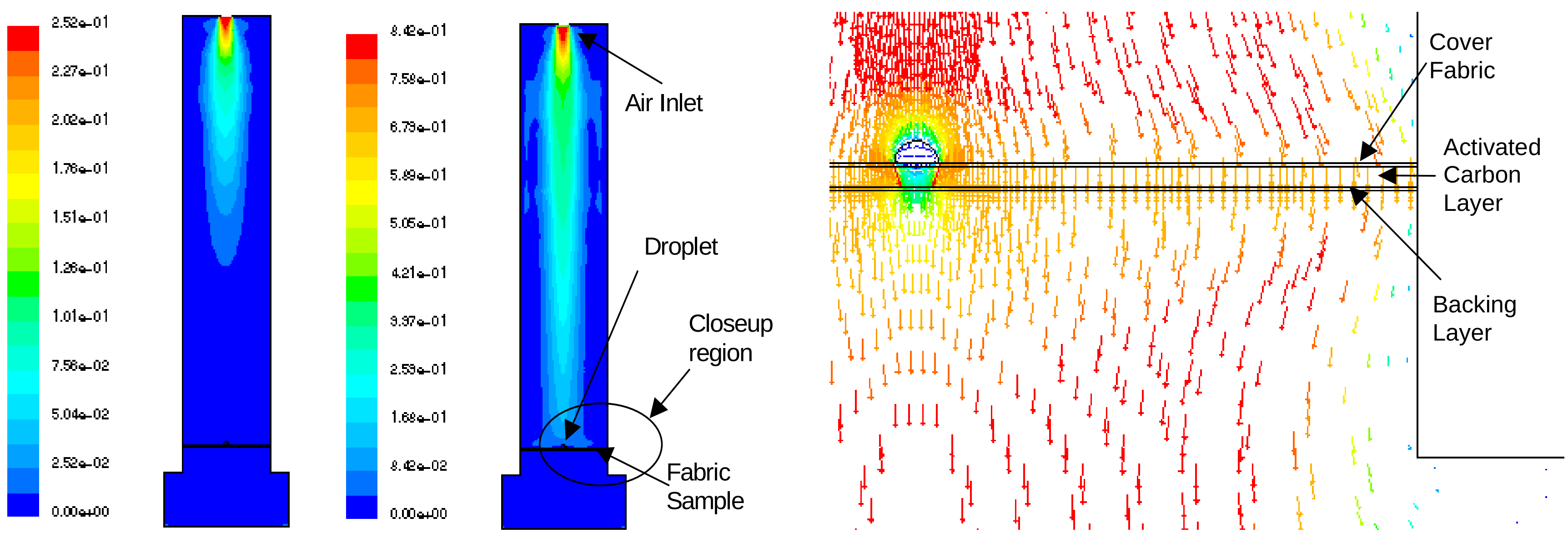


- **Commercial Wipe:**
  - **70% Polypropylene**
  - **30% Cellulose Wipe**
- **Agreement Within Property Uncertainty**



Activated Carbon

- **AVLAG Swatch Test Cell Geometry**
- **Single MeS Droplet (1μL, 30°C) Enables 2-D**



0.3 L/min **1.0 L/min**

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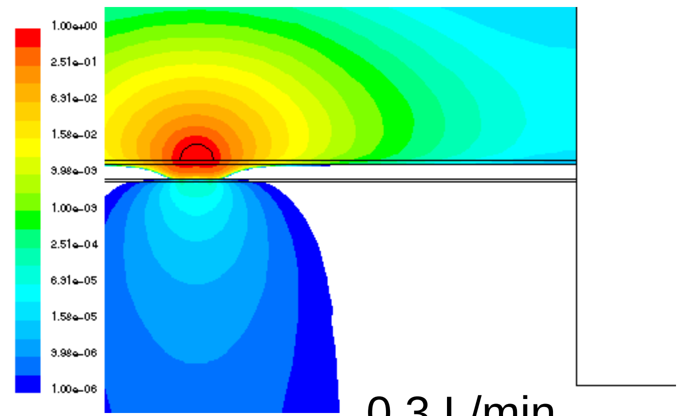
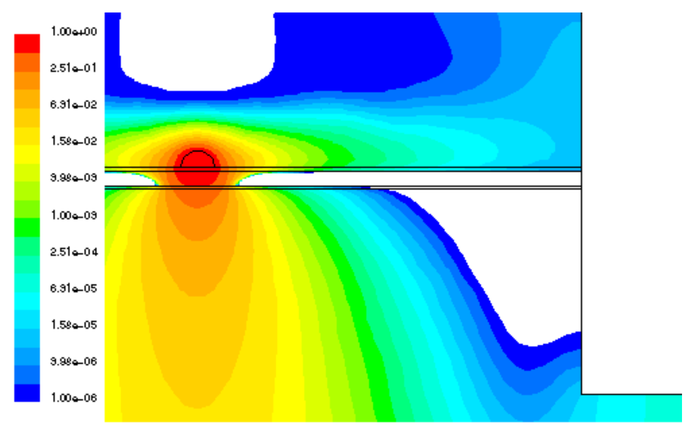
Effect of Flow Rate on Penetration

- **Local Overload of Activated Carbon Allows Penetration**
- **Higher Flow Velocity**
  - **Inhibits Vapor Spread Above Fabric**
  - **Faster Breakthrough**
  - **Larger Integrated Penetration**
- **Consistent with Data**

P_{vap}/P_{sat} at 180 Minutes

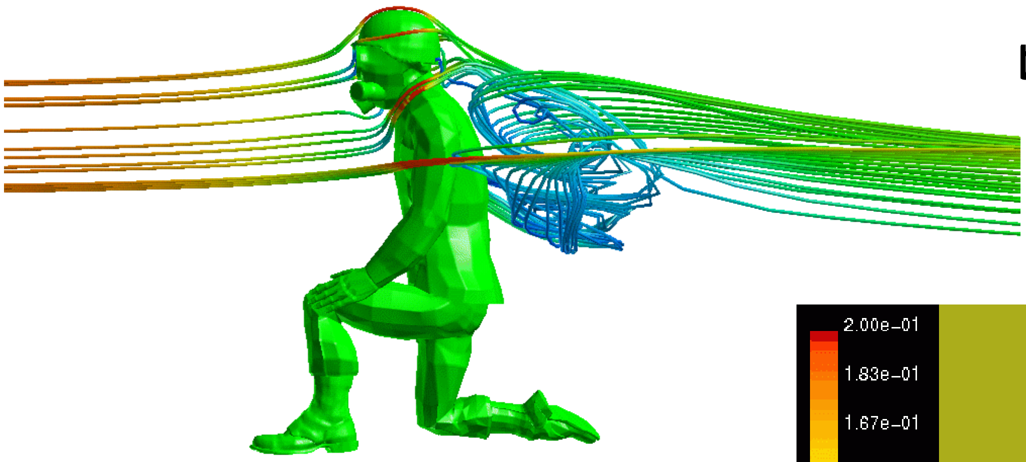


0.3 L/min



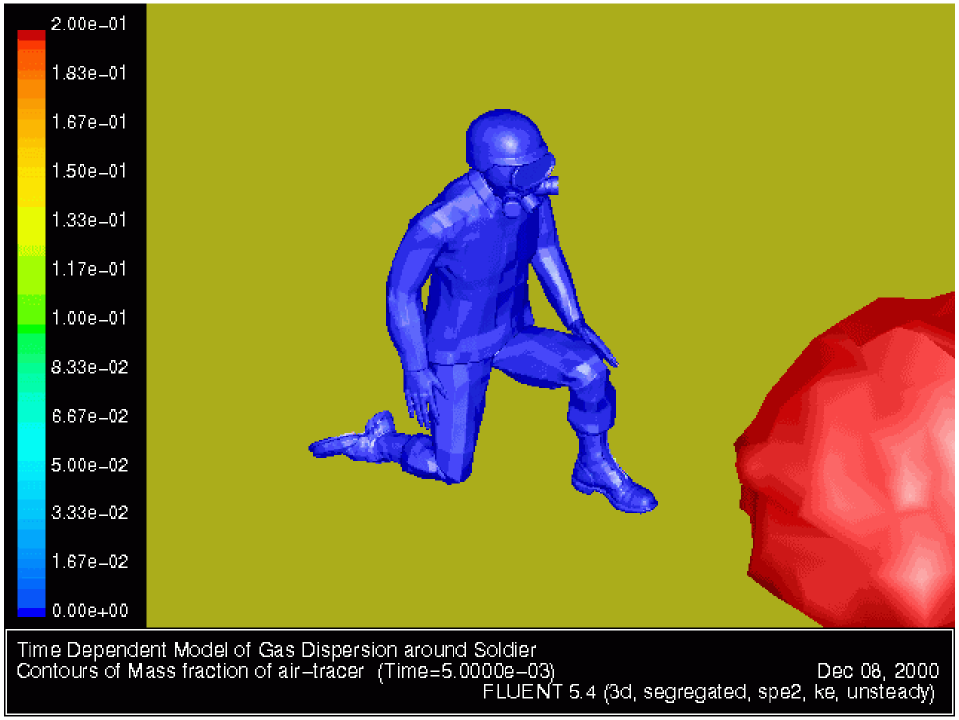
1.0 L/min

Example Calculations with Kneeling Soldier



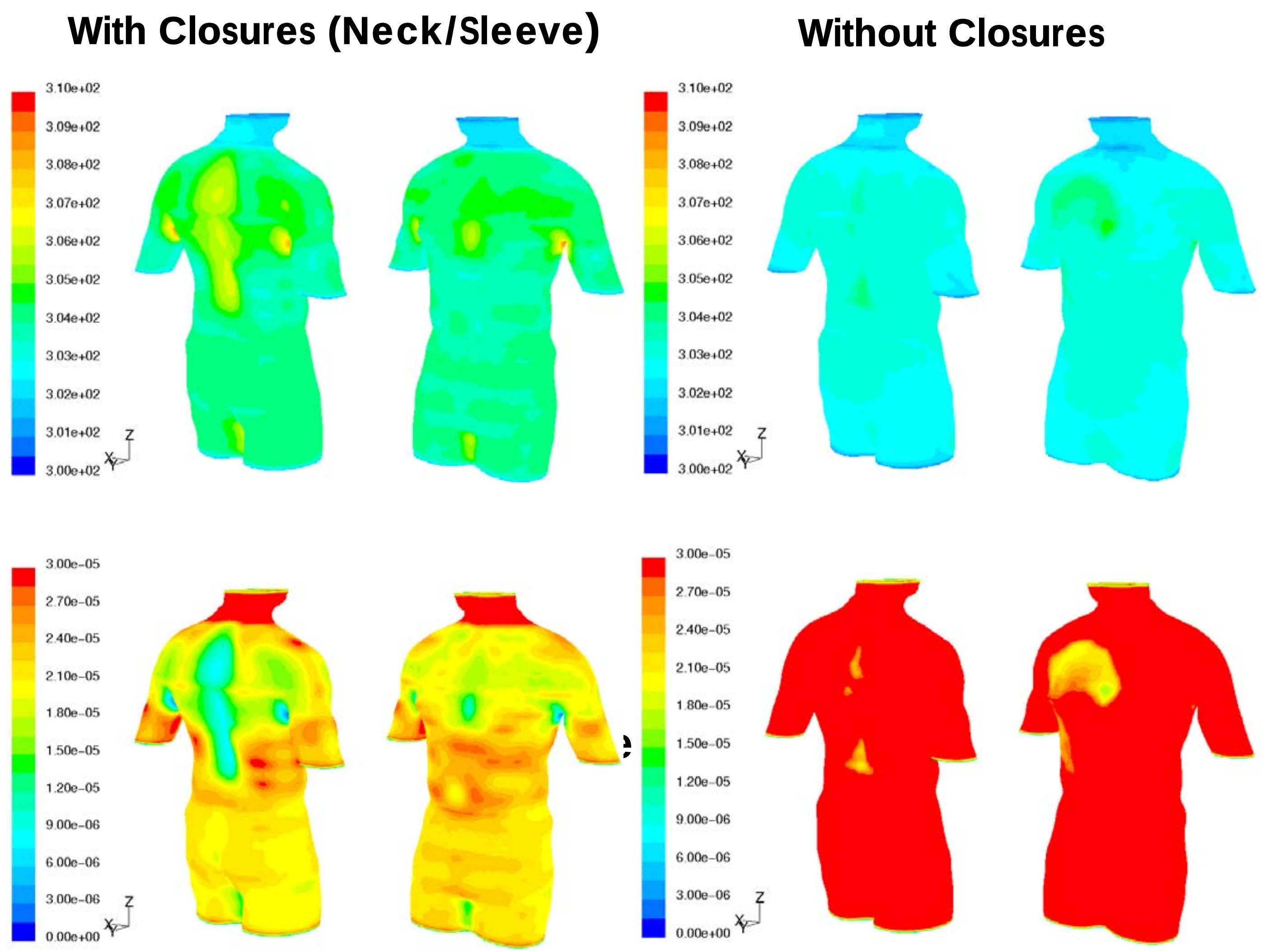
treaklines for Steady 10 mph Headwind

1 m Spherical Gas Cloud Passing Over Soldier



Thermal Balance Simulations

5 mph Wind
27°C
70% RH



Future Applications

- **Applications to CB Protective Clothing Design/Evaluation**

  Possible Topics:

  - **Comparisons of Fabric**
  - **Layering Strategy**
  - **Closure Design**
  - **Aerosol Contamination**
  - **Radiative Heat Loads**

- **Related Work Proposed or Underway**
  - **Support CBART Swatch Test Development**
  - **Steam/Heat Fabric Test Apparatus**

- **Commercial/Industrial Applications**

- **Looking for Opportunities for Design/Test Support and Data Comparisons**